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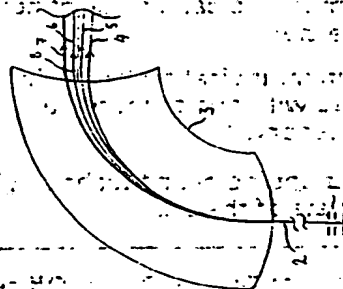
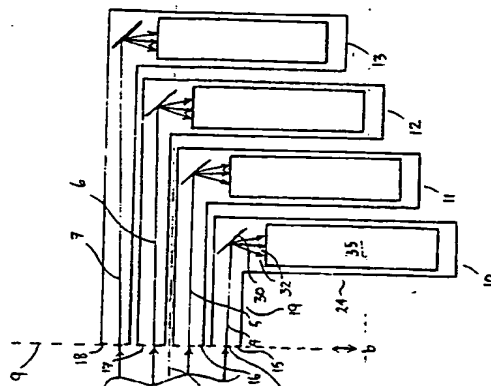
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(54) **Multiple-detector system for detecting charged particles.**

(57) A multiple charged-particle detector system includes a plurality of charged-particle detector assemblies (10-12) which are each made up of a first arm (19-22) and a second arm (24-27) extending at an angle to each other. Charged particles (4-7) enter an aperture (14-18) at the entrance of the first arm (19-22) of each detector assembly (10-12) and strike a dynode (30-33) positioned at the intersection of the two arms causing electrons to be emitted by the dynode (30-33). Some of the electrons pass into the second arms (24-27) of the detector assemblies (10-12) and are detected by a continuous-dynode electron multiplier (35-38). The first arms (19-22) are narrower than the detectors (35-38), and the detector assemblies (10-12) are arranged in such a way that the minimum separation at which charged-particle beams (4-7) can be detected is determined by the widths of the said first arms (19-22) of the detector assemblies (10-12), and not by the widths of the detectors (35-38) themselves.



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This invention relates to multiple-detector systems for detecting charged particles. It is particularly, although not exclusively, relevant to multiple-detector systems used in spectrometers, for example Isotope-Ratio Mass Spectrometers which are used for the determination of the isotopic composition of materials.

Many analytical devices involve the simultaneous detection of charged particles at a plurality of locations. In order to do this, an array of charged-particle detectors may be used. The minimum size of these detectors is a limiting factor in determining the minimum spacing apart at which the detectors may be positioned, and thus the minimum spacing at which particles may be detected, and this spatial limitation poses a problem which must be solved in designing the device. Another frequent requirement of multiple-detector systems is that the detectors be adjustable in their relative positions, so that charged particles may be simultaneously detected at a plurality of locations, the spacings of which locations may be varied. An example of a field in which both these requirements must be met is isotope-ratio mass spectrometry.

Isotope-ratio mass spectrometers are well known in the prior art. Typically, such an arrangement will consist of an ion source for generating a beam of ions which are characteristic of the element (or elements) in the sample to be analyzed; a mass analyzer for dispersing the ions in the beam to follow different trajectories according to their mass-to-charge ratios; and a plurality of ion detectors, each of which is positioned to detect ions of a particular mass-to-charge ratio. The mass analyzer, for example a sector magnet, effectively separates the incident ion beam into a plurality of dispersed beams which are focused at different points on the focal plane of the magnet, the points at which particular particle beams are focused on the focal plane being determined by the mass-to-charge ratios of the particles. In such a device, a plurality of particle beams may be detected simultaneously, giving a rapid and accurate measurement of the isotopic composition.

For a given mass spectrometer configuration, the spacing between the positions at which ions are detected will vary depending upon the different mass-to-charge ratios of the various isotope beams to be measured. Typically, the distance between isotope beams to be detected is in the range of a few millimetres, so that the detectors employed must be capable of detecting ion beams only a few millimetres apart.

One type of ion detector which may be used is the continuous-dynode electron multiplier. A continuous-dynode electron multiplier is a tube of high-resistivity glass which has the property that when a charged particle strikes it, secondary electrons are emitted. The secondary electrons in their turn hit the inner wall of the tube and this process is repeated causing more and more emissions, so that at the output end of the tube a large electron signal is detected. Typically, the tube is curved and diminishes in cross-section along its length. It is possible to manufacture continuous-dynode electron multipliers which are small enough to be placed a few millimetres apart, but these have some drawbacks in that they are not as reliable as the larger models, they are more expensive to produce and they do not have a large dynamic range (i.e. a constant response over a wide range of intensities) which is very important in isotope ratio analysis where the ratios of adjacent peak heights may be greater than 1,000,000 : 1.

Another method for detecting ion beams which are very close together is to use a channel-plate detector. A channel plate is typically a disc of high-resistivity semiconducting glass with many tiny pores, which are the openings of tiny channels through the plate, each channel acting as a continuous-dynode electron multiplier. A channel plate may have thousands of pores per square millimetre and would therefore have no difficulty in detecting beams a few millimetres apart. Channel plates do however have drawbacks. The lifetime of channel plates is poor as they tend to burn out after a while. Also, the existence of the pores affects the observed peak shape, which depends on the position at which the ion beam strikes the plate surface.

In order to be able to look at the isotopic composition of a plurality of different materials, another desirable feature of isotope-ratio mass spectrometers is that the ion detectors be adjustable in their relative positions, because, as stated above, for a given mass spectrometer configuration the positions of the ion beams to be detected will vary according to the mass-to-charge ratios of the isotopes in question.

An isotope-ratio mass spectrometer incorporating many of the above features is shown in US4524275 (Cottrell et al), which is incorporated herein by reference. In this device, an ion source produces a beam of ions which are dispersed by a sector magnet and detected by a plurality of ion detectors. The magnet is shaped so that the dispersed ion beams are focused on a plane which is substantially perpendicular to the optical axis. As discussed in the patent, this arrangement addresses a number of the defects found in prior isotope-ratio mass spectrometers. Sensitivity and accuracy are increased because the arrangement of the collector slits avoids the problem of off-axis beams striking part of an up-stream detector assembly and being deflected into a down-stream detector, giving a spurious signal. Further, the fact that the detectors are arranged along a plane which is substantially perpendicular to the optical axis simplifies the mechanical linkages required to alter the positions of the detectors. However, this device suffers from the prior art problem that the minimum spacing of the detectors across the focal plane is limited by their size.

It is an object of the present invention to provide a multiple-detector system for detecting multiple beams of charged particles in an analytical device which is simple in its construction and in which particles can be

detected at positions which are separated by distances smaller than the widths of the detectors.

It is another object of the present invention to provide a multiple-detector system for use in an analytical device, in which particles can be detected at positions which are separated by distances smaller than the widths of the detectors, the said multiple-detector system being simple in its construction and having charged-particle detectors which are reliable, have a long lifetime and a large dynamic range.

It is still another object of the present invention to provide a mass spectrometer having such a multiple-detector system.

In accordance with the above-mentioned objects, the invention provides a multiple-detector system for detecting a plurality of charged-particle beams in an analytical device, the detector system having at least one group of charged-particle detector assemblies, characterised in that each detector assembly comprises an apertured member for receiving one of the charged-particle beams, a secondary-emissive element which emits secondary particles in response to being hit by charged particles and is positioned so as to intersect the path of a charged-particle beam entering the detector assembly through the apertured member, and a detector for detecting particles emitted by the secondary-emissive element, the detector extending at an angle to the beam path between the apertured member and the secondary emissive element, the system further being characterised in that the detector assemblies are configured so as to enable the apertured members of the group of detector assemblies to be positioned in such a way that the minimum separation at which separate charged-particle beams can be discriminated is less than the widths of the detectors within the detector assemblies.

In a preferred form, the assembly comprises a first arm having the aperture at one end thereof, and a second arm, at an angle to the first arm, having the detector therein, the secondary emissive element being positioned at a junction between the two arms, with the first arm being narrower in width than the detector.

Viewed from another aspect the invention provides a mass spectrometer having a vacuum housing containing

In a preferred form, the assembly comprises a first arm having the aperture at an end thereof, and a second arm, at an angle to the first arm, having the detector therein, the secondary emissive element being positioned at the junction between the two arms, with the first arm being narrower in width than the detector.

i. a charged-particle source, typically an ion source, for producing a charged-particle beam, typically an ion beam,

ii. a mass analyzer for dispersing the charged-particle beam so that the incident charged particles are dispersed along different trajectories according to their mass-to-charge ratios, the dispersed charged-particle beams being focused by the mass analyzer along a plane, with charged particles of different mass-to-charge ratios being focused at different points along the said plane, and

iii. a multiple-detector system as defined above.

The apertures of the said detector assemblies may be positioned advantageously to coincide with the focal plane of the dispersed charged-particle beams, so that the dispersed charged-particle beams are focused on the said apertures.

In one embodiment, the said second arm of each detector assembly may be positioned substantially at right angles to the said first arm of each detector assembly with each of the said second arms extending away from the said first arms in substantially the same direction, with the lengths of the first arms of the various detector assemblies within the or each group progressively increasing by more than the widths of the said second arms so that the detector assemblies within each group may be nested together.

In another embodiment there may be two groups of detector assemblies, with the second arms of the detector assemblies of both of the said groups being substantially parallel to each other, but with the second arms of one group of detector assemblies extending in substantially the opposite direction to the second arms of the other group of detector assemblies, in order to form two back-to-back groups of nested detector assemblies. Alternatively, the said second arms of each detector assembly may not be substantially parallel, but may extend in directions at angles to each other.

In a further embodiment, each said detector assembly is adjustable in position along the focal plane of the charged-particle beams so that charged particles may be detected at varying positions which may be at varying distances apart.

The first arms may be made long enough to substantially prevent off-axis particles from reaching the detector to thereby improve the collimation of the beam before it hits the secondary-emissive element.

The charged-particle detectors may be channel electron multipliers. Alternatively they may be any other suitable charged-particle detector. In a further embodiment, one or more groups of conventional detector assemblies, for example Faraday cups or channel electron multipliers, may be provided in addition to the one or more groups of detector assemblies as disclosed in the present invention, and arrangements may be provided so that by altering the characteristics of the mass analyzer, the dispersed charged-particle beams are

detected by different groups of detectors. According to one aspect, the said secondary-emissive element may be a dynode, the secondary particles emitted by the said dynode being electrons.

Advantageously, the characteristics of the mass analyzer are chosen so that the focal plane of the dispersed charged-particle beams is substantially flat and substantially perpendicular to the optical axis, for example using the configuration shown in US4524275, although the invention is not limited to such a configuration.

The invention also extends to a detector assembly itself for use in the above systems.

Certain preferred embodiments of the invention will now be described in detail by way of example only and with reference to the figures, wherein:-

- Figure 1 is a plan view showing the ion optical arrangement of one type of single-focusing multiple-detector mass spectrometer which is constructed in accordance with the present invention;
- Figure 2 is a front view of a multiple-detector assembly suitable for use in the spectrometer of Figure 1, with a front cover of detector assembly 10 being omitted for clarity;
- Figure 3 is a sectional view along the line AA' in figure 2;
- Figure 4 is a plan view showing a further embodiment of the present invention;
- Figure 5 is a plan view of a still further embodiment of the present invention showing two groups of detectors arranged back-to-back; and
- Figure 6 is a front view of a four-detector assembly as shown in Figures 1-3, incorporated in a mass spectrometer.

It will be appreciated that this invention is not limited to a detector assembly for a mass spectrometer as shown in figures 1, 4, 5 and 6 but can be applied to many types of analytical devices having a plurality of detector assemblies arrayed next to each other. Further, although figures 2 and 3 show a channel electron multiplier, the invention is not limited to such detectors but may be used with any suitable detector. Also, the invention is not limited to a device wherein the focal plane of the dispersed beams is substantially perpendicular to the optical axis as shown in the figures, but may also be applied to a device where the said focal plane is at a different angle to the optical axis. In such a device, the detector assembly apertures would be positioned at the foci of the dispersed beams on a plane which is non-perpendicular to the optical axis. In such a device, mechanisms might be provided to adjust the position of the detector apertures in a direction parallel to the said plane, although as pointed out in US4524275 this would involve more complex engineering since the motion required would be at an inclined angle to the optical axis. The figures are not drawn to scale.

Referring to Figure 1, charged particles are generated in the charged-particle source 1 (which may be of any suitable type) which generates a charged-particle beam, typically an ion beam, said charged particles following trajectory 2 towards a mass analyzer 3. The incident ion beam is dispersed by the mass analyzer into beams of ions of different mass-to-charge ratios which follow trajectories 4, 5, 6 and 7 respectively. The beam of ions having the lowest mass-to-charge ratio which it is desired to measure, which follow trajectory 4, is focused at aperture 14 which is positioned on the focal plane 9. In the best mode of realizing the invention, mass analyzer 3 is a sector magnet of the type disclosed in US4524275, wherein the magnet is shaped so as to focus the dispersed ion beams on a focal plane which is substantially perpendicular to the optical axis 8. The ion beam passes through aperture 14 in apertured plate 15 of detector assembly 10 to enter the first portion (arm) 19 of the detector assembly. The ions then travel along the first portion of the detector assembly and strike a secondary-emissive element which consists of a dynode 30 placed at the junction between the first 19 and second 24 portions (arms) of the assembly. Ions striking dynode 30 generate secondary electrons 32, some of which pass into the second portion (arm) 24 of the detector assembly 10. These electrons are detected by detector 35. Ions of progressively higher mass-to-charge ratios will follow trajectories 5, 6 and 7, to enter detector assemblies 11, 12 and 13 respectively. Any or all of detector assemblies 10-13 may be adjustable in position along the focal plane 9 of the mass spectrometer (see arrow b).

Figures 2 and 3 show simplified views of a multiple-detector assembly according to the invention. Figure 2 is drawn looking along the optical axis 8 towards detector assemblies 10-13, with front cover 80 (see Fig.3) of detector assembly 10 removed to show detector 35. Detector assembly 10 is made up of a housing 40 which can be moved along runners 45 and 50 via micrometer shaft 55. Housing 40 contains a detector, in this example a channel electron multiplier 35. Output from the detector is via connecting wire 61, the power supply to the detector being via wires 60 and 62. Charged particles enter the detector assembly through an aperture 14 in apertured plate 15 and pass along the first portion 19 of detector assembly 30 as described above (See figure 3). They then strike dynode 30, generating secondary electrons which enter the mouth of detector assembly 35 and strike the inner walls, generating secondary electrons. The process is then repeated as described above, and an amplified signal representative of the electron signal is outputted on wire 61. Apertured plates 16, 17 and 18 belong to detector assemblies 11, 12 and 13 respectively, all of the detector assemblies being constructed in a similar manner. The lengths of the first portions 19-22 of detector assemblies 10-13 progres-

sively increases in order that the detector assemblies may be nested together.

Figure 4 shows a mass spectrometer similar to that shown in Figure 1, but with an additional group of charged-particle detectors 110-113. Source 1 generates a beam of charged particles which follows trajectory 2 to enter the mass analyzer 3, which disperses the incident charged-particle beam. The characteristics of mass analyzer 3 may be switched so that the dispersed charged-particle beams may follow either trajectories 4, 5, 6 and 7 (shown by broken lines) or trajectories 104, 105, 106 and 107 (shown by unbroken lines); to enter detectors 10-13 or 110-113 respectively. Detectors 110-113 are conventional detectors, for example Faraday Cups or Channel Electron Multipliers, while detectors 10-13 are constructed according to the invention. In this way a selection between different types of detectors is possible.

Figure 5 shows a further embodiment of the present invention. In this example, the charged-particle beam entering the mass analyzer 3 has been dispersed to follow eight trajectories, 200-207. The dispersed beams are detected by two groups of detectors constructed according to the invention, 210-213 and 214-217 respectively. The second portions of the detector assemblies of both of these groups are substantially parallel to each other, but with the second portions of one group of detector assemblies extending in substantially the opposite direction to the second portions of the other group of detector assemblies, in order to form two back-to-back groups of nested detector assemblies. The detectors are adjustable along runners 245-248 by micrometer shafts 260-267 respectively. The arrangement of the two groups of detectors in this example allows two detectors to share the same upper and lower runners.

If desired, the second portions of one group of detector assemblies need not be parallel to those of the other but they may be arranged at an angle. Neither is it necessary for the second portions within one group to be parallel to each other. For example, the second portions 211-213 and 215-217 in Figure 5 could be splayed out within the 180° arc to the right of portions 210 and 214.

Figure 6 is a front view of a four-detector assembly, as shown in Figures 1-3, incorporated into a mass spectrometer. A vacuum housing 250 has four pairs of upper and lower runners (only one pair of which, 45 and 50, can be seen in Figure 6) supporting four detector assemblies, 10-13. Each detector assembly, e.g. 10, is connected via a drive shaft, e.g. 55, to a drive mechanism, e.g. 255. These are bellows-driven micrometer drives which are attached to ports in the vacuum housing 250 by gold wire sealed flanges, only one of which, 252, can be seen in Figure 6. The drive mechanism may be controlled by a single control system, e.g. a computer (not shown).

Many alternative arrangements of the detector assemblies are possible in addition to those shown in the figures. For example, the angle between the first and second portions of the detector assemblies may not be a right angle. Also, second portions of the detector assemblies need not be parallel to each other.

## Claims

1. A multiple-detector system for detecting a plurality of charged-particle beams in an analytical device, the detector system having at least one group of charged-particle detector assemblies, characterised in that each detector assembly comprises an apertured member for receiving one of the charged-particle beams, a secondary-emissive element which emits secondary particles in response to being hit by charged particles and is positioned so as to intersect the path of a charged-particle beam entering the detector assembly through the apertured member, and a detector for detecting particles emitted by the secondary-emissive element, the detector extending at an angle to the beam path between the apertured member and the secondary emissive element, the system further being characterised in that the detector assemblies are configured so as to enable the apertured members of the group of detector assemblies to be positioned in such a way that the minimum separation at which separate charged-particle beams can be discriminated is less than the widths of the detectors within the detector assemblies.
2. A multiple-detector system as claimed in Claim 1, wherein the charged-particle beams are dispersed to follow different trajectories according to their mass-to-charge ratios, each detector assembly being disposed so as to detect a beam of particles of a particular mass-to-charge ratio.
3. A multiple-detector system as claimed in Claim 2, wherein the analytical device comprises a charged-particle focussing system having an optical axis, each said charged-particle beam being focussed at a point; said points being disposed at various locations on a focal plane, said detector assemblies being arranged so that the focal point of a particular charged-particle beam substantially coincides with the aperture of a particular detector assembly.

4. A multiple-detector system as claimed in claim 3, wherein the focal plane of the charged-particle beams is substantially flat and substantially perpendicular to the direction of the optical axis at the exit of the focussing system.
- 5 5. A multiple-detector system as claimed in any preceding claim, wherein each detector assembly comprises a first arm having the apertured member at one end, and a second arm, at an angle to the first arm, having the detector therein.
6. A multiple-detector system as claimed in claim 5, wherein the second arms of the detector assemblies are substantially parallel to each other, the lengths of the first arms of the detector assemblies within the or each group progressively increasing by more than the widths of the second arms so that the detector assemblies within each group may be nested together.
- 10 7. A multiple-detector system as claimed in claim 5 or 6, wherein the second arm of each detector assembly extends substantially at right angles to its first arm.
- 15 8. A multiple-detector system as claimed in claim 7, wherein two groups of detector assemblies are provided, with the second arms of the detector assemblies of both of the groups being substantially parallel to each other, but with the second arms of one group of detector assemblies extending in substantially the opposite direction to the second arms of the other group of detector assemblies, in order to form two back-to-back groups of nested detector assemblies.
- 20 9. A multiple-detector system as claimed in claim 5 or 6, wherein the second arms of each detector assembly extend in various directions so as to be splayed out around the optical axis.
- 25 10. A multiple-detector system as claimed in any of the previous claims, wherein each detector assembly is adjustable in position so that charged particle beams may be detected at varying positions which may be at varying distances apart.
- 30 11. A mass spectrometer having a vacuum housing containing
  - i. a charged-particle source for producing a charged-particle beam;
  - ii. a mass analyzer for dispersing the charged-particle beam so that the incident charged particles are dispersed along different trajectories according to their mass-to-charge ratios, the dispersed charged-particle beams being focussed by the mass analyzer along a plane, with charged particles of different mass-to-charge ratios being focussed at different points along the plane; and
  - 35 iii. a multiple-detector system as defined in any of the preceding claims.
- 40 12. A multiple-detector system for detecting a plurality of charged-particle beams comprising at least one group of charged-particle detector assemblies, characterised in that each detector assembly comprises a first arm having an entrance aperture at one end thereof, a second arm at an angle to the first arm and having a detector therein, and a secondary-emissive element positioned at a junction between the two arms and emitting secondary particles on being hit by a charged particle beam entering through the first arm aperture, at least some of the emitted secondary particles being detected by the detector in the second arm, the first arm being narrower in width than the detector.
- 45 13. A charged-particle beam detector assembly comprising an entrance aperture, a secondary emissive element positioned so as to be hit by a charged-particle beam entering the assembly through the entrance aperture and emitting secondary particles when so hit, and a detector for detecting said secondary particles, said detector extending at an angle to the beam path between the aperture and the secondary-emissive element.
- 50 14. A charged-particle beam detector assembly according to claim 13, wherein the assembly comprises a first arm having the aperture at one end thereof, and a second arm, at an angle to the first arm, having the detector therein.

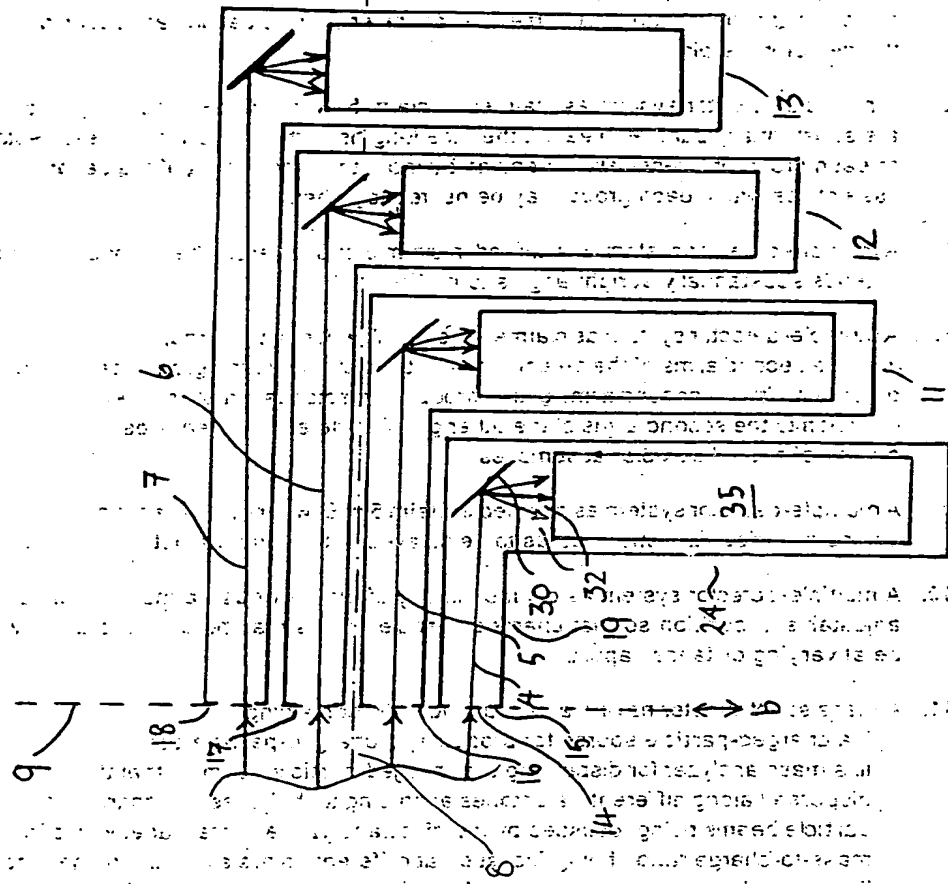
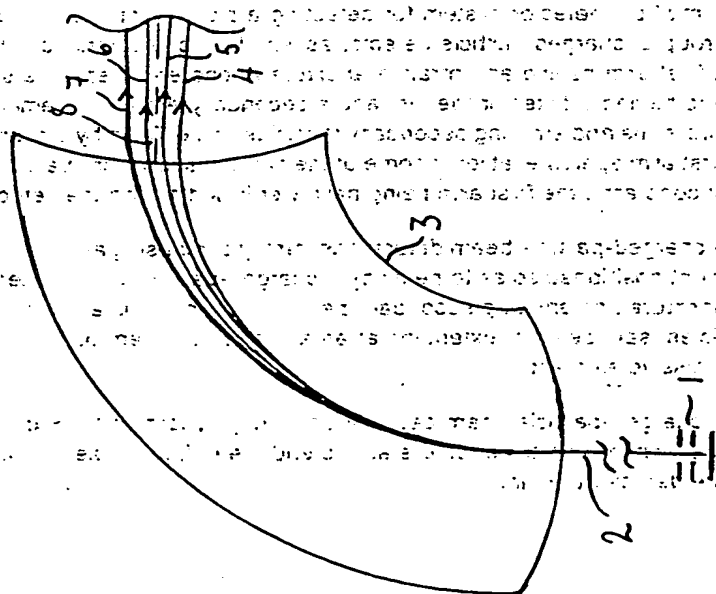


FIG. 1. 1044



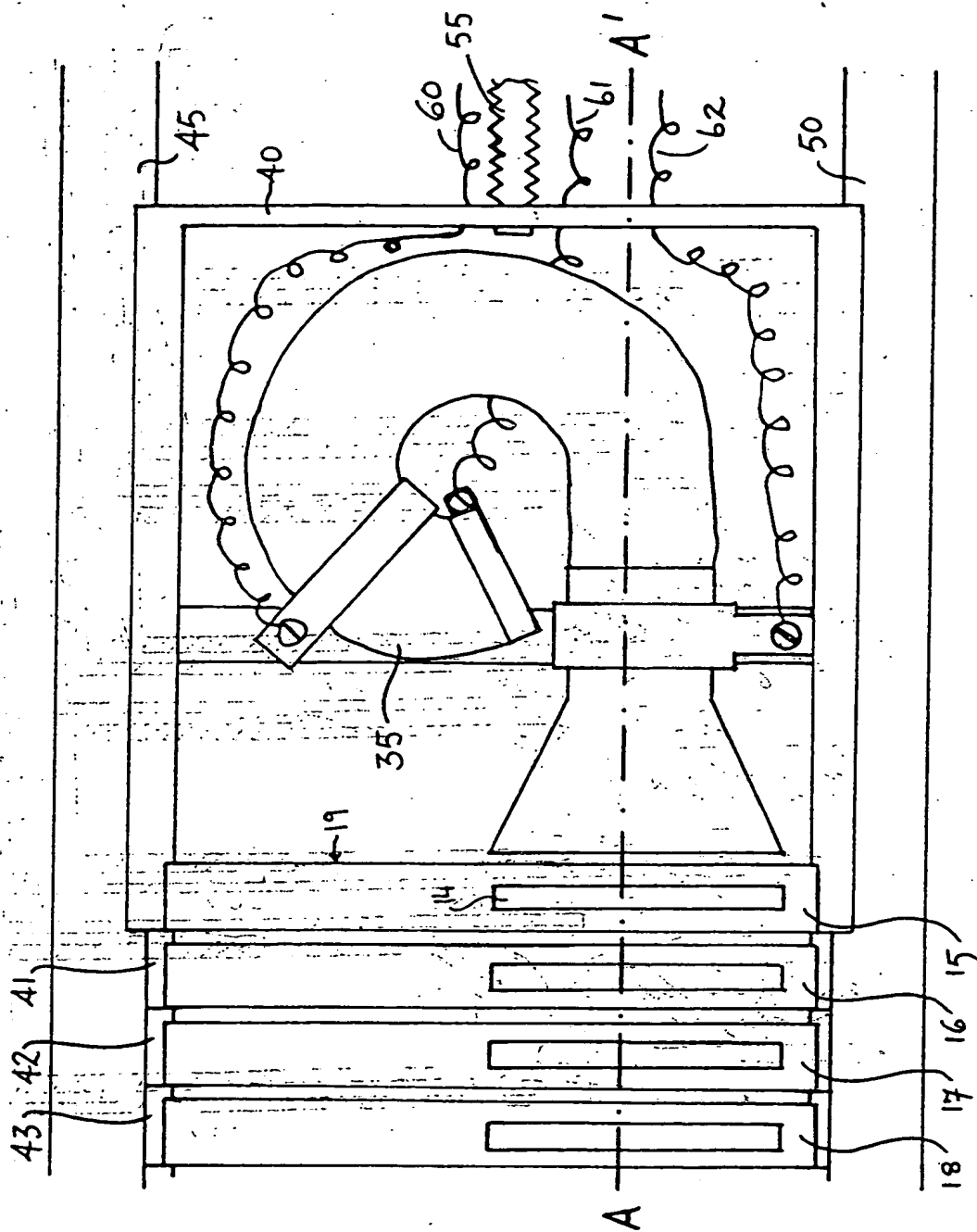


FIG. 2.



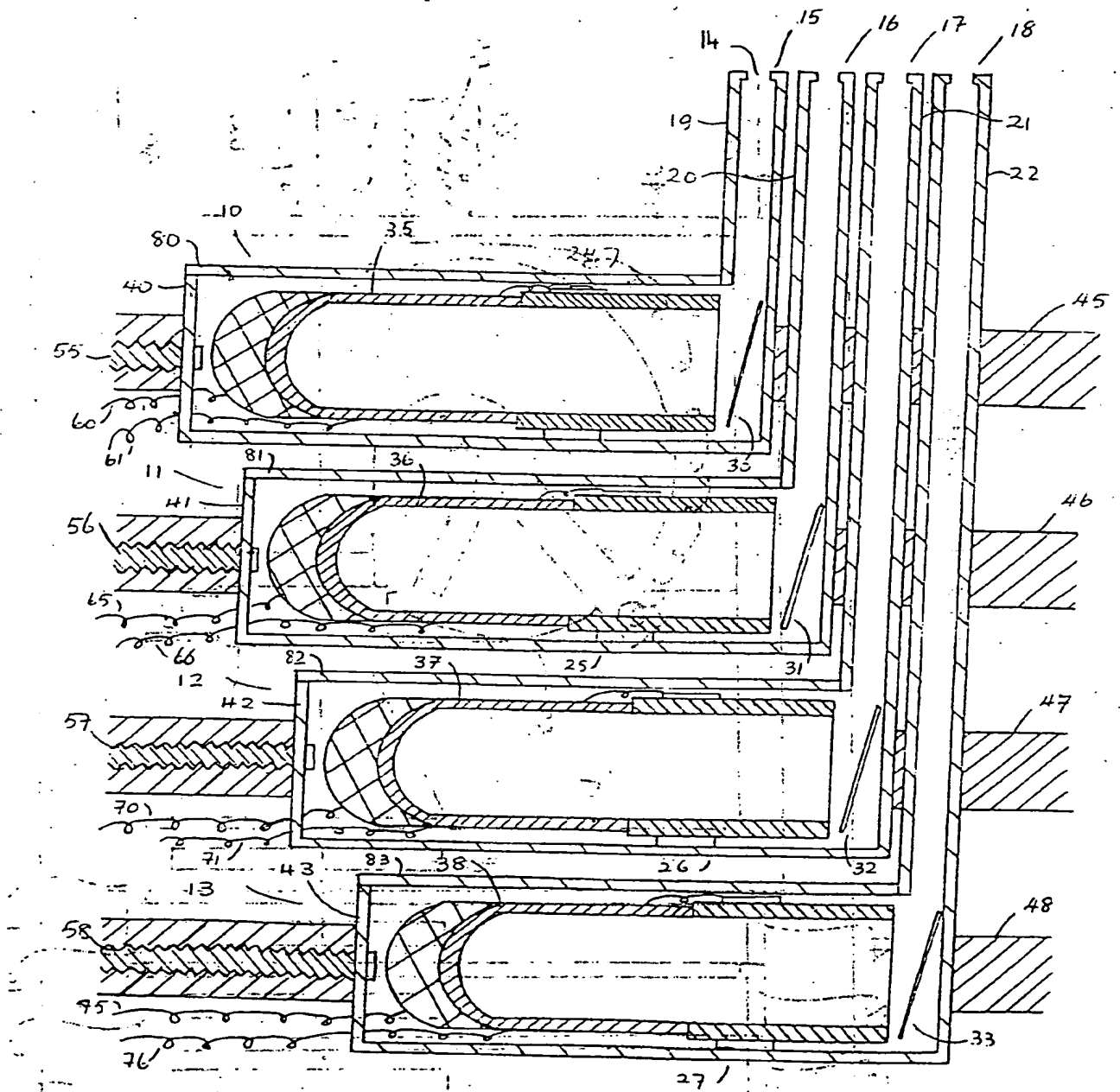


FIG. 3

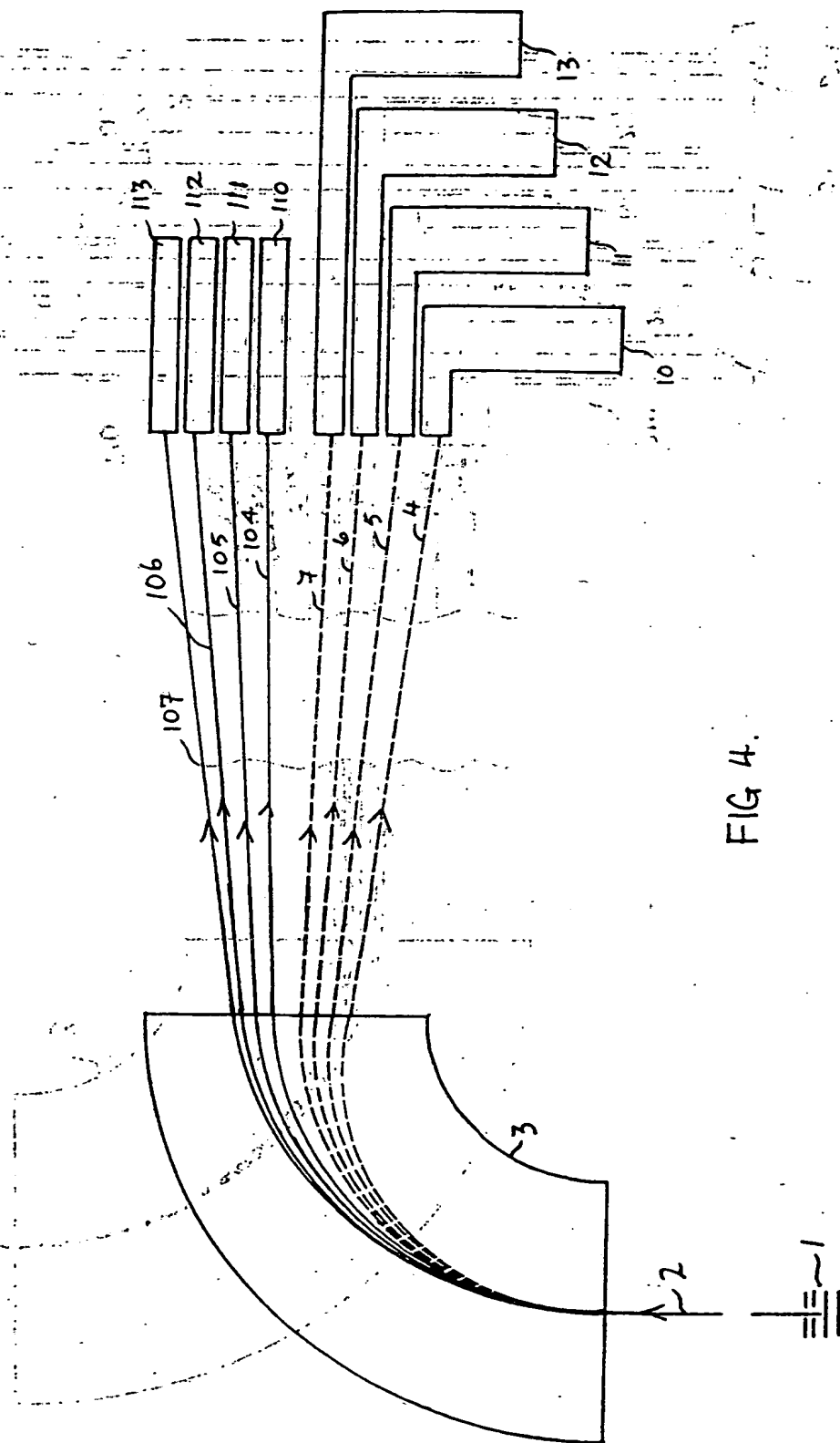


FIG 4.

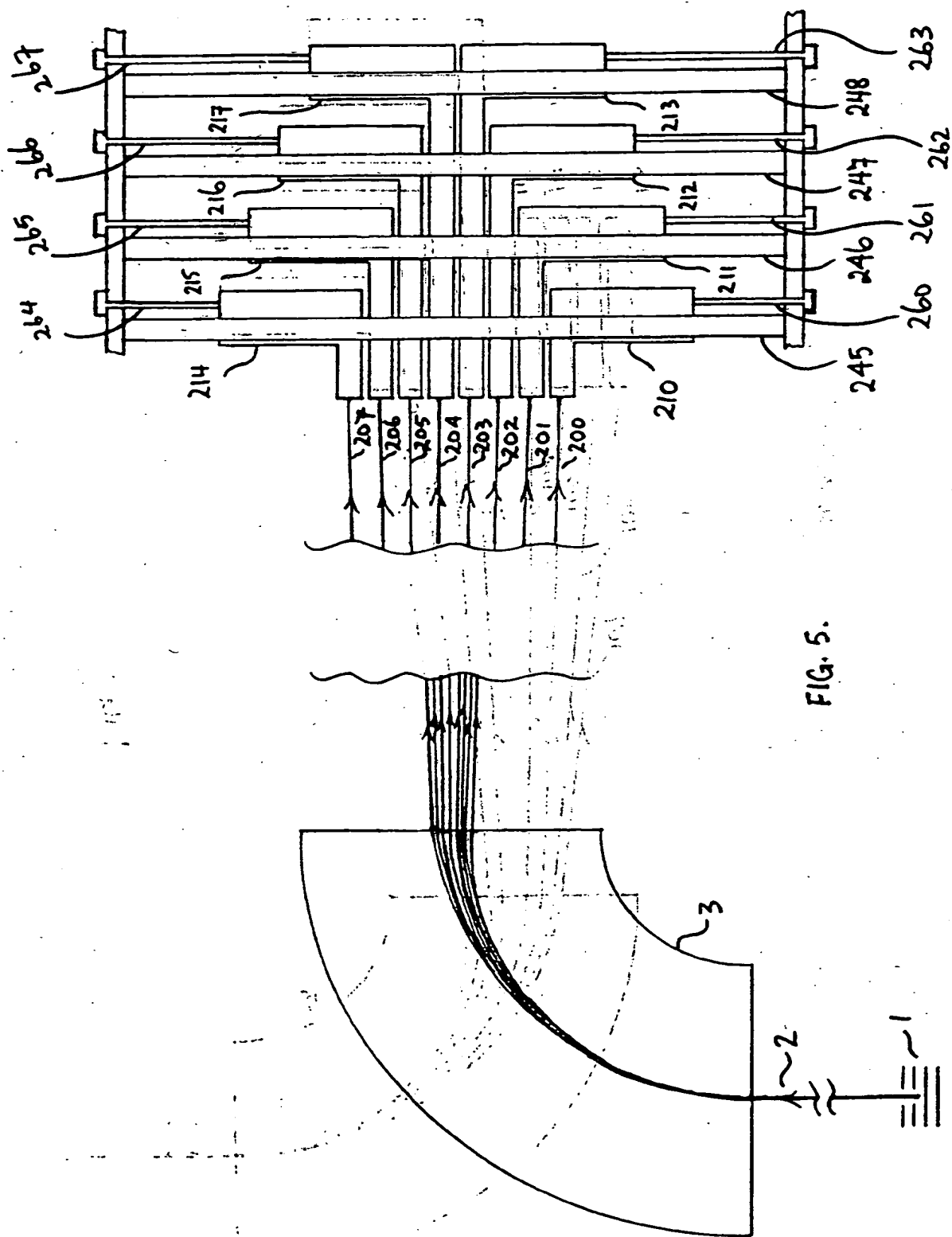


FIG. 5.

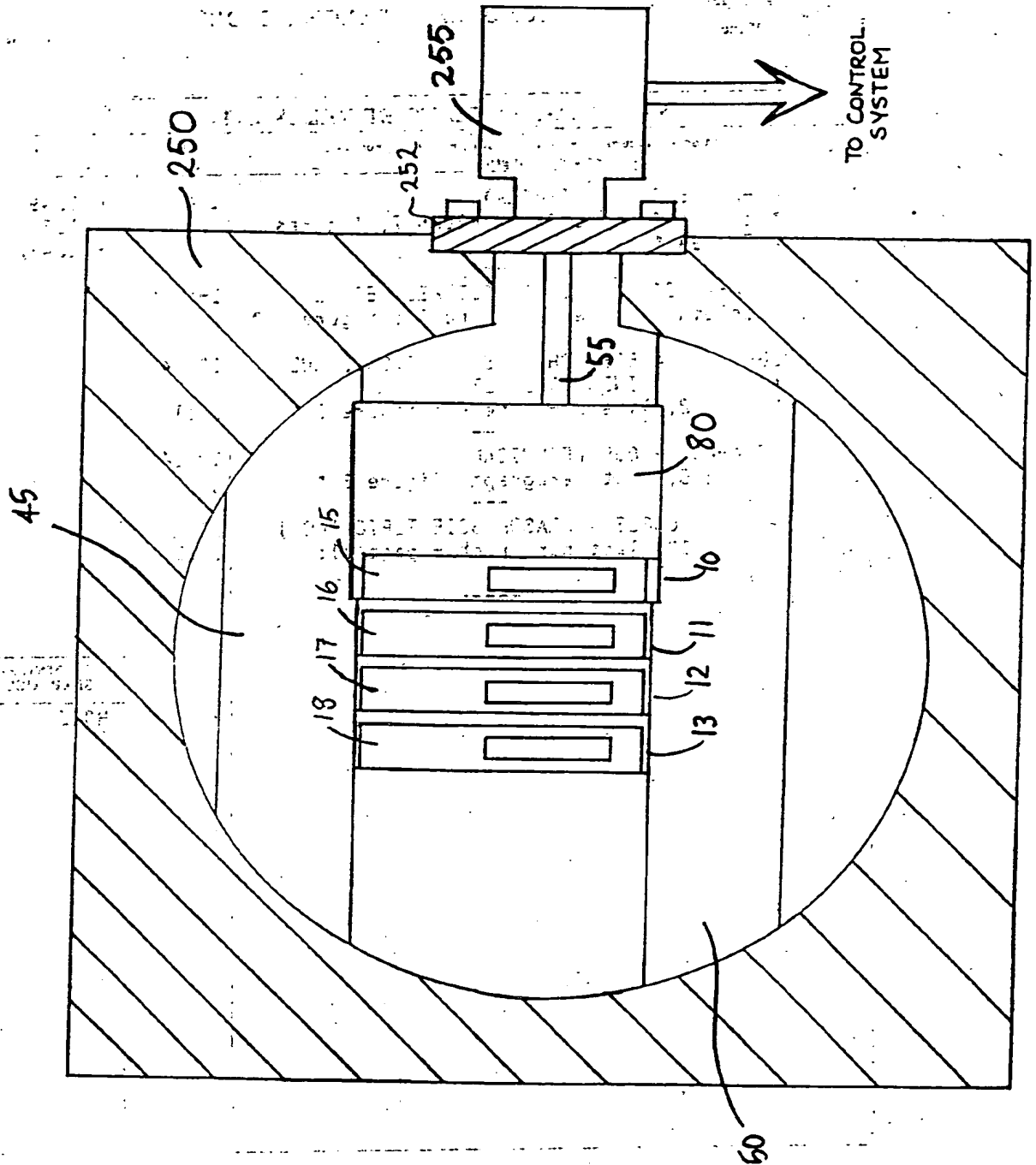


FIG. 6



European Patent  
Office

# EUROPEAN SEARCH REPORT

Application Number  
EP 94 30 1048

## DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
Y A	EP-A-0 509 887 (CAMECA) * column 4, line 49 - column 7; figures 4, 7, 8, 9A *	1-4, 10 11	H01J49/02 H01J3/04 H01J43/04
D, Y	US-A-4 524 275 (J. S. COTTRELL ET AL.) * column 4, line 35 - line 63; figure 1 *	1-4, 10	
X A	GB-A-1 114 535 (PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LTD) * page 2, line 9 - line 42; figure 1 *	13, 14 1, 11	
X	DE-A-40 19 005 (FINNIGAN) * page 5, last paragraph; figure 3 *	13, 14	
X A	WO-A-89 00883 (PHRASOR SCIENTIFIC INC.) * page 10, last paragraph - page 11; figure 5 *	13 1, 11	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)
			H01J
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 27 May 1994	Examiner Hulne, S
CATEGORY OF CITED DOCUMENTS			
<p>X : particularly relevant if taken alone  Y : particularly relevant if combined with another document of the same category  A : technological background  O : non-written disclosure  P : intermediate document</p> <p>T : theory or principle underlying the invention  E : earlier patent document, but published on, or after the filing date  D : document cited in the application  L : document cited for other reasons  &amp; : member of the same patent family, corresponding document</p>			

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As a part of the program to develop a new type of aircraft engine, the Department of Defense has authorized the development of a new type of aircraft engine. This program is being carried out by the Department of Defense, the Department of the Army, the Department of the Navy, and the Department of the Air Force. The program is being carried out by the Department of Defense, the Department of the Army, the Department of the Navy, and the Department of the Air Force. The program is being carried out by the Department of Defense, the Department of the Army, the Department of the Navy, and the Department of the Air Force.

